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Transit accessibility, land development and socioeconomic priority: A typology of planned station catchment areas in the Greater Toronto and Hamilton Area

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Abstract: The Greater Toronto and Hamilton Area is in the process of implementing a wide array of transit expansion projects. Despite being an important evaluator of transit efficacy, accessibility is not a typical variable included in the business cases of the local planning authorities. We address this shortcoming by computing current and future accessibility scores for each proposed transit route and station. Our results are compared against measures of availability of developable land within station catchment areas and the socioeconomic priority of populations residing within catchment areas. A typology of station types is produced via a multi-criteria analysis, and this is further used to assess the efficacy of the transit plans in meeting the redevelopment and intensification goals and social priorities in the region. We are able to conclude that significant mismatches between accessibility and developable land exist. Furthermore, there is a lack of alignment between accessibility and socioeconomic priority; however, where these two criteria align, risks of redevelopment-based gentrification are low, due to the unavailability of readily developable land in these station catchment areas.

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1 Introduction

The Greater Toronto and Hamilton Area (GTHA) is experiencing a public transit transformation. In the past ten years, the region has undertaken diverse initiatives to develop an integrated transit system with the goal of benefiting areas of recent population growth and economic expansion. As is shown by initiatives such as The Growth Plan for the Greater Golden Horseshoe (Ministry of Infrastructure, 2006) and The Big Move (Metrolinx, 2008), the Ontario Government is interested in developing a well-organized transportation system in the region.

In 2013, Metrolinx, the public transportation agency of the Province of Ontario, released *The Big Move Baseline Monitoring Report* (Metrolinx, 2013). The document reviewed the progress made since *The Big Move*. In it, Metrolinx offers their objectives for improving accessibility and mobility for all residents in the region, while simultaneously revitalizing the neighborhoods surrounding the transit station

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areas. The report listed the Top Priority Transit Projects with an allocated budget of CAD$16 billion for development and construction; some of these projects such as the Union-Pearson (UP) Express are already completed, and the rest are in various stages of development. The report also presented a list of Next Wave projects, some of which have been elevated to top priority, such as the Hamilton Light Rail Transit (LRT) and the Hurontario-Main LRT.

A recent survey of transit users shows that 90% of all respondents identified transportation as one of the main issues in the GTHA (Metrolinx, 2015). Moreover, 47% of the total transit users expressed dissatisfaction with the services. These numbers are not particularly surprising, as the average transit commute time in the region is 52.4 minutes (Metrolinx, 2015). To offer a contrast, the City of New York has an average commute time of 48 minutes, almost 5 minutes less than the GTHA (Perlman & Brown, 2013). Significantly, 43% of "lone drivers" would be willing to change their commute mode to transit if the system improved. These numbers reveal not only the discontent with the current transit provision but a latent population willing to switch to transit use if it were enhanced. The province intends to improve transit in light of the failure of the existing infrastructure to fulfill the demands of transit users and support the projected population growth of the GTHA.

A recent white paper in the region contained a comparison of transit expansion options for Scarborough, a former municipality now contained within the City of Toronto (Sorensen & Hess, 2015). The report evaluates several scenarios for their degrees of spatial coverage, with a particular emphasis on the availability of land for urban redevelopment and intensification within each hypothesized station area. The study found little opportunity for redevelopment in many catchment areas due to the prominence of single-detached homes within a post-war suburban streetscape, a land use considered stable, and not a high priority for redevelopment according to the Toronto zoning regime, but did show that significant development opportunities exist along arterial corridors where LRT lines are planned. The current paper extends this work by expanding the study to include a complete set of next-wave transit projects across the entire GTHA and by including two new analysis layers: changes in accessibility due to transit, and the socioeconomic composition of station areas. It is our intention for these new analysis directions to create a more complete assessment of the proposed transit lines being developed in the region.

This research evaluates eight proposed transit lines (140 stations) in the GTHA to measure their potential impacts on accessibility, their influence on land-use change, and the socioeconomic characteristics of station areas. We are interested in determining the following:

1) What are the likely impacts of the new transit developments on station-area accessibility levels, and how might this impact land use redevelopment?
2) What is the current land-use availability for redevelopment within the catchment areas of new stations?
3) What are the socioeconomic characteristics of the population located within station catchment areas, with a specific emphasis on lower socioeconomic status?
4) With the above measurements in place, how can they be used to score the relative merits of the 140 stations evaluated in this research?

The purpose of this research is to provide an evidence-based evaluation method to prioritize and assess transit plans in the region, especially those that have already been subjected to business case evaluations used by the province for cost-benefits analysis.

The next section of this paper contains a brief review of the pertinent literature. A description of the study area follows in section 3, and the methods are described in section 4. Section 5 contains the results of our analyses, including an assessment of the multi-criteria evaluation conducted. The paper concludes with a brief summary and discussion in section 6.

2 Literature review

The literature review is divided in three sections. The first section describes the concept and measurement of accessibility. The second section explains the Land-Use Transport Cycle with a focus on the land use and accessibility relationship. Finally, the third section reviews the empirical literature connecting rapid transit with land-use change.

2.1 Accessibility

In the transportation literature, accessibility is commonly defined as the potential for interaction (Hansen, 1959). The study of accessibility implies an analysis of how easily opportunities can be reached according to their spatial distribution (Handy & Niemeier, 1997). This terminology should not be confused with mobility, which only describes the ability to move from one place to another (El-Geneidy & Levinson, 2006). Furthermore, mobility and accessibility are not necessarily correlated. Having high levels of mobility do not suggest effective accessibility (El-Geneidy & Levinson, 2006). Rather, accessibility exists at the intersection of mobility and land-use, and it is the combinations of mobility levels, with land-use densities that give rise to different levels of accessibility (Páez, Mercado, Farber, Morency, & Roorda, 2010).

The level of accessibility will depend on the subjects doing the travel (demographic and socioeconomic characteristics), the amount and diversity of destinations, the location of the potential users, the travel efficiency to reach activities (time or money), and the travel mode choice (automobile, transit, bicycle, walking) (Cascetta, Cartenì, & Montanino, 2013; Handy & Niemeier, 1997). These characteristics are closely related to transportation planning as they address subjects such as land-use distribution, infrastructure development, economic and environmental impacts, mode of transportation and social equity (Manaugh & El-Geneidy, 2011).

Measuring accessibility has become a fundamental element for any transportation planning assessment, as it helps evaluate the appropriateness and effectiveness of a transportation proposal as well as the impacts that it could have on the land use in a given area (Geurs & Van Wee, 2004; Handy & Niemeier, 1997; Levinson & Krizek, 2005).

Accessibility can be categorized into two types of measurements: passive and active accessibility (Cascetta et al., 2013). On the one hand, passive accessibility refers to how many users can reach a specific location, defining the level of attractiveness of a certain area. Increased passive accessibility would mean that there are more people that could reach a specific location in a given timeframe. If a location becomes more available, developers may construct additional services, businesses, and activities to accommodate the needs of this new incoming population. On the other hand, active accessibility describes how easy it is for a person to reach destinations. Increased active accessibility of a certain location would suggest that the population adjacent to it could reach more 'opportunities' such as jobs, schools, and malls. This augmented active accessibility would make this location more attractive for residential development as people would likely desire to live there because they could reach services and activities in a suitable timeframe.

2.2 Accessibility and land use

As described above, changes in active or passive accessibility levels may influence land development and the relocation of individuals and firms into the affected areas. As such, the transportation and land-use dynamic is best expressed by the "transportation land-use cycle" (Giuliano, 2004; Wegener & Fuerst, 1999). The cycle (Figure 1) should be read in the following way: the distribution of land uses determines the location of human activities; the spatiotemporal patterns of activites give rise to transportation demands; the infrastructure and technology of these transport systems will facilitate accessibility; and changes in accessibility have the potential to influence the location decisions of developers, firms, and residents. Within the narrower context of this paper, we highlight the final phase of the cycle, the potential influence of changing accessibility on land-use development – due to transit improvements – within station catchment areas.

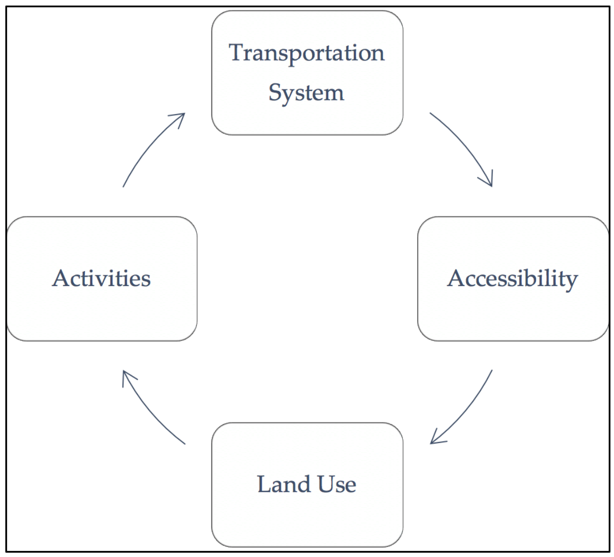

Figure 1: Transportation land-use cycle

2.3 Transit and land-use development

Studies that investigate the impact of transit on land-use change apply a variety of methods including surveys, field observation, accessibility measurements, and hedonic price models (Badoe & Miller, 2000; Cervero & Duncan, 2002; Vessali, 1996). In a large analysis of the rapid transit and land-use research literature, Vessali (1996) established that "most of the studies reviewed had some level of land-use change resulting from transit improvements" (Pg. 88). However, he remarked that the observed impact varied in accordance with the methodology and variables included in the study.

A case study by Cervero and Duncan (2002) in Santa Clara, California, explored the impact on commercial land values of light and commuter rail services. The authors use a hedonic price model to identify commercial land value variations according to proximity to light and commuter rail services. As part of their findings they identify that land value increased in the parcels near the stations, having the highest rise within 0.25 miles. Increased land values are a strong indication of market demand, and a reasonable proxy for the increased attraction to developers as well.

In a similar study, Hurst and West (2014) analyzed the effects of light rail infrastructure on land use in Minneapolis, Minnesota. The study compared three stages: before construction, during construction and during operation. A GIS methodology was employed to identify land-use changes on a city-wide level and the potential land-use changes within the proximities of the LRT corridor. In the former case the results showed no significant land-use change at any stage, while in the latter the results provided evidence that, during operation, land-use conversion increased on industrial and single-family housing sites.

Calvo, de Oña, and Arán (2013) explore the same issue by analyzing the evolution of Madrid's subway from 2000 to 2010 and the impacts it had on population and land use. This research indicates that transit effects are more noticeable in the medium and long term. Two lines were assessed using GIS and statistical software. The results obtained showed greater changes when land-use planning and transit were developed together. With the subway line extensions, the areas surrounding the stations saw population growth, indicating the land developments were residential.

These research examples provide evidence of the influence of transit on land use. Even though the methods applied were different, all of them relied on accessibility as an important variable to define potential land development. Thus, accessibility enabled by transit proves to be a variable that exerts a significant influence on future land-use distributions, and we use this finding to support our decision to use accessibility change as a measure of redevelopment potential for station areas. Moreover, we follow previous work in the region to include station-area measurements of land-use redevelopment potential, based on availability of suitable lands (Sorensen & Hess, 2015), and likewise consider the socioeconomic distribution of accessibility benefits as an additional dimension of analysis relevant to the GTHA planning context (Foth, Manaugh, & El-Geneidy, 2013; Hertel, Keil, & Collens, 2015; Kramer, Borjian, Camargo, Graovac, & Falconer, 2017).

3 Study area

The GTHA amalgamates six municipalities: Toronto, Hamilton, Durham, Halton, Peel and York. According to the 2011 national census, the total population for the GTHA is over 6.5 million people and is one of the fastest growing urban areas in Canada. The province has asked the GTHA to plan to accommodate a further 2 million residents by 2031 and part of this growth planning includes the provision of new rapid transit infrastructure. The current levels of rapid transit provision can be found in Figure 2. As illustrated, Toronto is the only part of the region with subways and streetcars, and all other municipalities are connected internally and to Downtown Toronto via GO commuter rail and an extensive bus network.

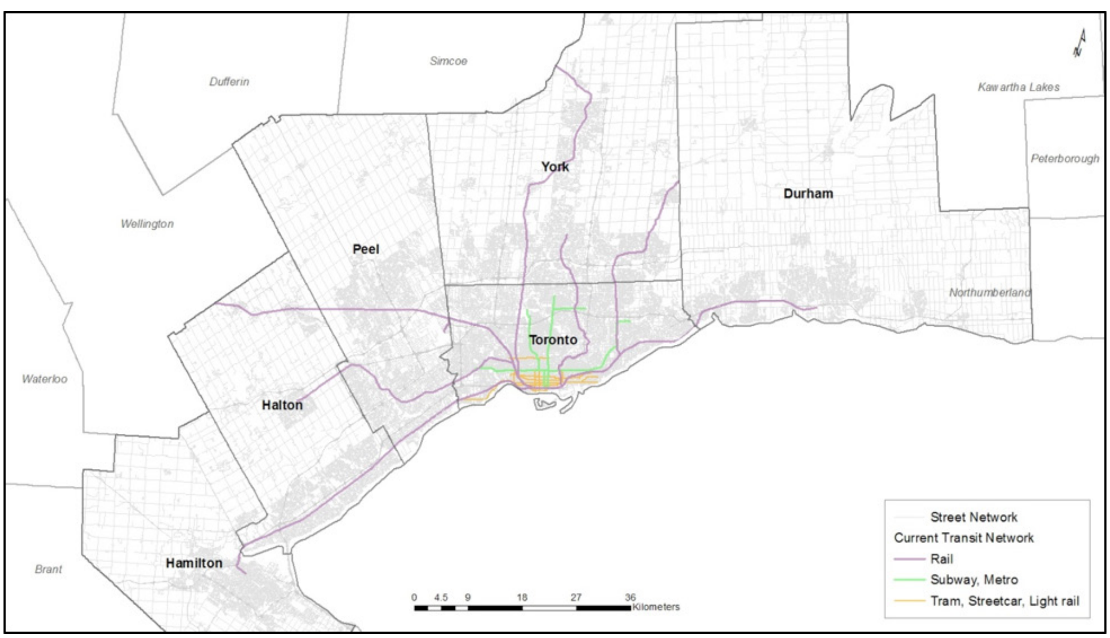

Figure 2: GTHA — current transit provision

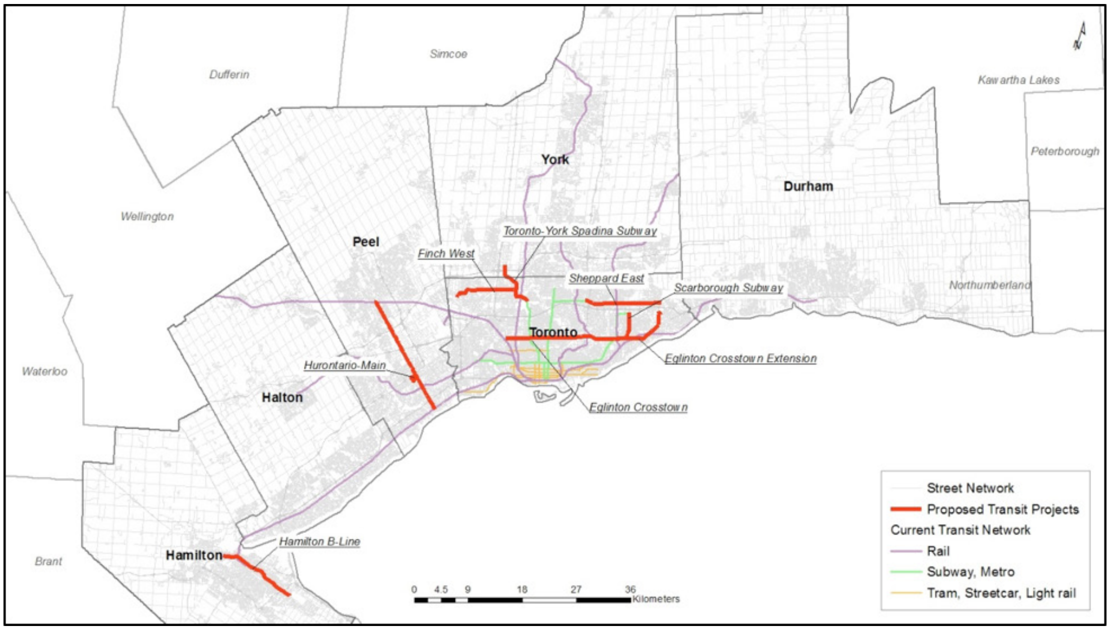

Figure 3: Proposed transit lines

Taking into consideration the projected economic and population growth in the GTHA, Metrolinx has plans, in various stages of development, for rapid transit expansions. This research will focus on the six Light Rail Transit and two Subway extension projects proposed for the region (Table 1).

Table 1: Description of proposed transit lines evaluated

Transit Line	Type	Length (Km.)	Number of Stations	Budget (Billion CAD)	Est. Year of Completion
Eglinton Crosstown	LRT	19	25	5.3	2021
Eglinton Crosstown Extension	LRT	11	18	1.7	2021
Finch West	LRT	11	19	1.0	2021
Hamilton B Line	LRT	13.7	18	1.2	2019
Hurontario-Main	LRT	23	26	1.6	2022
Sheppard East	LRT	13	27	1.0	2021
Scarborough Subway	Subway	7.6	1	3.6	2023
TYS Subway Extensiona	Subway	8.6	6	3.2	2017

Sources: Metrolinx Transit Project Fact Sheets, Metrolinx Benefit Cases, City of Toronto Staff Report.
TYS = Toronto York Spadina

Figure 3 maps the selected transit projects. Six projects: 2 subway lines and 4 LRTS, are concentrated in Toronto. The other 2 LRT projects are in Peel and Hamilton. Transit projects such as the Downtown Relief Line, Regional Express Rail, Smart Track and Bus Rapid Transit proposals in York and Mississauga were not chosen for this study for a variety of reasons. Some projects do not have detailed enough plans or have not been approved, and for many, the information found in their respective Business Case and Fact Sheets was not definitive or detailed enough to be used in a geographical information system (GIS) model.

4 Methodology

4.1 Data

The overall research plan is to compare indicators of accessibility change between the current and future levels of service provision to measures of land-use availability and socioeconomic status of station areas. This research required multimodal transportation data to model network travel times in a Geographic Information System (GIS). This included street network files and General Transit Feed Specification (GTFS) packages for the 6 regions under study in the GTHA. To compute land availability, land-use information at the parcel level was obtained from a private research database collected by researchers at the University of Toronto (Sorensen & Hess, 2015). Census data from the 2011 National Household Survey was used to describe the socioeconomic priority of station catchment areas within an 800-meter (or 10-minute walking) buffer. Finally, workplace destinations used in the accessibility measurements were obtained from the 2011 Transportation Tomorrow Survey (TTS). Both population and job counts are provided by the TTS at the level of Traffic Analysis Zone (TAZ) centroid. Even though centroids do not perfectly represent the spatial distribution of population or employment within a zone, TAZs in the GTHA are smaller than Census Tracts, limiting the potential for bias arising from the Modifiable Areal Unit Problem (Openshaw & Taylor, 1979).

4.2 Creation of multimodal networks

Two networks were developed for this research and will be referred to as the Current and Future networks. The first uses the information taken from a snapshot of transit services provided by GTFS packages for Tuesday, June 30, 2015. The network was created in ArcGIS, using the popular toolbox Add GTFS to Network Dataset (Farber, Morang, & Widener, 2014). This set of tools allows researchers to use detailed information of transit schedules in a GIS model to calculate origin to destination travel times, and with it improve the quantification of accessibility.

The Future network is similar to the Current network, but adds to it the services provided by the 8 aforementioned transit projects. Metrolinx Fact Sheets, Business Cases, City of Toronto Staff Reports and alternative websites were employed to digitize the transit lines and their respective stations. The Future scenario augments the current network with the digitized transit lines and stations. This means that we have not made other changes to the transit network, such as the realignment or removal of buses that will occur with the proposed transit expansions. This level of detail was not available in the literature, and the amount of network editing required was not possible within the budget and timeframe of this project. The impact of these omissions on estimated travel times is not expected to be very large because the proposed transit expansions will run at faster speeds and higher frequencies than existing buses making shortest paths along the potentially removed bus lines very unlikely in the future network scenario.

Travel times for the proposed transit expansions were adopted from business cases according to transit mode: 32 km/h for subways, and 28 km/h for LRTs. A travel time penalty of half the published headway for each line was added to the connectors between the pedestrian and transit networks to simulate waiting times. This was only required for the Future transit lines as waiting times were automatically estimated from the GTFS schedules for all existing transit services.

4.3 Accessibility measurements

Geurs and Van Wee (2004) offer a detailed description of different methods developed to assess accessibility. Considering the current focus on accessibility enabled by public transit and its effect on potential land-use development at the new transit stations, the accessibility measurement that best addresses this problem is the cumulative opportunities measurement. This method is commonly used by planners and geographers (Geurs & Van Wee, 2004; Owen & Levinson, 2015) since it "examines accessibility as a spatial phenomenon by considering the costs and benefits of the potential trips offered by transportation systems between origins and destinations of interest" (Owen & Levinson, 2015, p. 111). For this research, we use the cumulative opportunities accessibility measurement to compute active and passive levels of accessibility at the 140 stations proposed for the region, using travel times derived from the Current and Future transportation networks. Each one of these networks will provide information about the number of potential opportunities that could be reached within 50 minutes, a willingness-to-travel threshold established in previous research for the GTHA (Metrolinx, 2015).

The first measure, the passive accessibility score, is calculated as the total number of people that can reach the new transit station via public transportation within a travel time threshold. It is defined as follows:

$$P_j = \sum_{i=1}^{n} R_i f(t_{ij})$$

where P_j is the passive accessibility of station j, R_i is the population of TAZ i, (t_{ij}) is the public transit travel time from TAZ i to station j at 8am, and $f(t_{ij})$ is an indicator function equal to one if t_{ij} is less than the threshold of 50 minutes and zero otherwise.

It is hypothesized that a station with a large expected increase in passive accessibility will face higher commercial redevelopment demands, and this location will have become more reachable by consumers and workers.

On the other hand, the active accessibility score is calculated as the total number of jobs reachable from the new transit stations via public transportation and walking. It is defined as follows:

$$A_j = \sum_{i=1}^{n} E_i f(t_{ji})$$

where A_j is the active accessibility of station j, E_i is the number of jobs in TAZ i, (t_{ji}) is the travel time from station j to TAZ i at 8am, and $f(t_{ji})$ is an indicator function equal to one if t_{ji} is less than the threshold of 50 minutes and zero otherwise.

Being able to reach more employment opportunities demonstrates the potential for residential development since more people would like to live in areas that offer greater access to jobs.

4.4 Developable land

An indicator of developable land was created for each station's catchment area. The 10-minute walkable area serves as a boundary to identify which parcels could be susceptible for redevelopment. Sorensen and Hess (2015) developed four categories of land use that are developable: retail uses (mostly low density retail types with extensive surface parking), parking lots, mixed-use parcels with retail on the ground floor and residential on the second floor; and vacant land. Parcel level land-use data are collected by the province, however, due to an ill-fated public-private partnership, a company in the region has a monopoly over the sale and use of this data for non-governmental purposes, making this data unavailable to university researchers. As a response, a privately collected land-use dataset has been assembled by researchers at the University of Toronto Scarborough, through exhaustive student fieldwork and remotely sensed imagery analysis. The data were initially collected with fieldwork in 2011 for all parts of the Greater Toronto Area (excluding Hamilton) and has received some updating since then. We conducted an additional quality check using satellite imagery within the station catchment areas developed for this research project, with a specific focus on determining whether parcels coded as developable show evidence of existing redevelopments. Using this updated land-use dataset, we calculated the percentage of each station catchment area that is currently coded as developable. Note that this dataset does not cover the City of Hamilton, and therefore the LRT line in this region could not be fully evaluated.

4.5 Socioeconomic priority index

The socioeconomic characteristics of a station area provide a means to evaluate whether the proposed transit lines service more vulnerable populations that are also more likely to rely on public transit for their daily mobility needs. For each catchment area, we use areal interpolation from the National Household Survey 2011 Census Tract data to construct a socioeconomic priority index based on the following variables:

- Percentage of households with income less than $30,000 per year
- Percentage population that immigrated to Canada within the last 5 years
- Percentage of the labor force that is unemployed
- Percentage of households that spend 30% or more of their income on shelter costs

These measures were drawn from a review of the literature focusing on transit-related social equity within Toronto and other similar socioeconomic contexts (Currie, 2010; Foth et al., 2013; Fransen et al., 2015). Importantly, the reader will notice that automobile ownership is not included in our measure of socioeconomic priority. We agree with the arguments put forward by Foth et al. (2013) that many disadvantaged families are forced into automobile ownership due to low access to public transit, and that there are many carless households by choice within the inner city. Combined, this indicates that automobile ownership is a better proxy of urban form than a direct indicator of deprivation. The variables were normalized into Z-scores at the census tract level, and then interpolated via a population weighted average for each station. The interpolated Z-scores were combined into a single measure by adding across the four measures.

4.6 Multi-criteria evaluation

After computing measures for three criteria: accessibility, developable lands, and socioeconomic priority, a multi-criteria evaluation (MCE) is used to categorize the station areas according to their performance across the multiple dimensions. To facilitate comparisons, a composite measure is created for each criterion, and then organized according to terciles (i.e. membership in high, medium, and low terciles). For accessibility, absolute changes in passive and active accessibility were standardized into Z-scores, added together, and split into terciles. The developable lands score only consisted of a single measure, percent of catchment area that is developable, and therefore required no further standardization before split into terciles. Finally, the socioeconomic variables, as described above, were standardized into Z-scores and added across the four measures, before being split into terciles. Our analysis follows by describing the distributions of stations according to their tercile memberships across the three dimensions of accessibility, developable lands, and socioeconomic priority.

5 Results

5.1 Overall description of measurements

A description of the measures calculated for each station area appears in Table 2. The table provides the mean and standard deviation of each raw measurement calculated, as well as the tercile break-points for the three measures used in the MCE. Looking at the summary of accessibility measures, we can observe that the transit plans tend to provide a greater percentage change in access to jobs (29.1%) than it does for passive accessibility (23.5%), but overall, there is a greater degree of passive accessibility than active. This may be explained by the relative locations of the transit projects in the region, with most passing through low-density residential lands, making access from populations to these station areas higher than access to jobs from these stations.

In terms of developable lands, there is only one measure, the percent of the station's catchment area that is currently developable. It is important to note that the mean value is quite low, at 12.4%, and when examining terciles, two thirds of the station areas have less than 16% developable lands. This is particularly concerning as it may be difficult to achieve coordination between rapid transit and densification given the current lack of easily developable lands in most station catchment areas.

Finally, the socioeconomic characteristics include four measures of vulnerability and transit dependence. By comparing the station areas to the entire GTHA region we immediately see that the areas serviced by the upcoming transit expansions have lower socioeconomic status than the region in general; an indication that the transit plans will have positive impacts on social equity overall. This may mostly be due to transit plans concentrating in the inner suburbs of Toronto, a region less affluent than both the core of the city as well as the newer suburbs outside of the City (Hertel et al., 2015; Hulchanski, 2010). The intersection of accessibility and socioeconomic priority examined in the MCE will shed more light on whether the higher or lower priority populations are receiving higher or lower levels of accessibility improvements.

Table 2: Description of evaluation measures

	Mean	Standard Deviation	Min	33rd	66th	Max
Accessibility						
Current Active	471,998	283,057	-	-	-	-
Future Active	598,214	345,327	-	-	-	-
Absolute Change Active	126,216	114,957	-	-	-	-
Percentage Change Active	29.1%	26.7%	-	-	-	-
Current Passive	806,465	1,006,802	-	-	-	-
Future Passive	332,587	451,756	-	-	-	-
Absolute Change Passive	200,337	165,912	-	-	-	-
Percentage Change Passive	23.5%	17.9%	-	-	-	-
Composite Score	0.00	1.85	-2.31	-1.09	0.13	6.31
Developable Land						
% Developable	12.4	11.3	0.0	9.0	16.0	59.5
Socioeconomic Priority						
% HHD Income < $30,000	26.5% (18.3%)[a]	9.4%	-	-	-	-
% Immigrated within 5 years	9.3% (6.2%)[a]	4.0%	-	-	-	-
% Labor Force Unemployed	10.8% (5.7%)[a]	2.6%	-	-	-	-
% 30%+ of Income on Shelter	34.7% (30.7%)[a]	6.3%	-	-	-	-
Composite Score	2.77	2.31	-3.53	1.86	3.42	8.09

[a] Figures in brackets pertain to the region wide averages for the GTHA

5.2 Accessibility

As is evident in Table 3, for each station we have computed four accessibility scores (i.e., current and future networks with active and passive measures), and two measures of change (i.e., absolute and percentage). This large number of results, while providing a very detailed assessment of the performance of the transit plans, cannot be easily communicated within the constraints of a research article. Instead, we summarize our results with an assessment of accessibility change per dollar invested for each transit line, and with a map of the composite accessibility score, per station, used in the MCE that follows.

Table 3 contains a summary of the accessibility changes and cost effectiveness of each transit line, expressed in terms of accessibility change per dollar invested. The total absolute change in accessibility is the sum of the absolute changes at individual stations for each line. This was then divided by the total expected budget of each line to arrive at the number of jobs and people that become accessible per billion dollars of estimated capital costs.

The table indicates that LRT lines are more cost effective than the subway extensions planned for the region. We caution that this finding is not necessarily generalizable to subways and LRTs more broadly, but rather the specific plans for subway development in this region tend not to be very cost effective. However, for the TYS subway, the large percentage increase in accessibility, to an otherwise poorly served area in the city, is quite noticeable. Despite this, the capital costs of subway tunnel construction push this project down the list in terms of cost effectiveness. In comparison, the two most cost-effective projects are at-grade LRTs located within Toronto's inner suburbs (Sheppard East and Finch West). These projects, along wide suburban arterials, achieve high gains in accessibility while keeping costs very low. On the other end of the scale, the Hamilton LRT and Scarborough Subway Extension are the least cost effective projects under review. The Hamilton line, while not being a very expensive project, provides little accessibility over and above the existing bus lines servicing this corridor. In fact, four out of 18 stations on this line show no estimated change in accessibility in our calculations. The Scarborough Subway suffers for a different reason. First, the terminal station of the line is currently serviced by a rapid transit line (SRT) running in an above-grade right-of-way. So, while there are absolute improvements in accessibility, these are mostly gained by the subway making fewer stops than the existing service, and that passengers will not be required to change vehicles where the SRT currently terminates at the Kennedy Subway station. Governments in the region have considered several alternative plans for replacing the SRT including a renovation of existing infrastructure and the replacement of the SRT with an LRT within the same right-of-way. Each of these is likely to provide a similar level of service that is provided by the current infrastructure, thus making our comparison of the current infrastructure to the most likely to be implemented solution, the Scarborough Subway, valid. Importantly, the Scarborough Subway Extension will require the excavation of a tunnel, at a very high cost, which does not appear to be reconcilable with the service level improvements estimated by our analysis.

Table 3: Accessibility per dollar invested

Line	Accessibility Change[a] Active	Accessibility Change[a] Passive	# Stations	Transit Lines Length (km)	Transit Lines Estimated Budget (Billions)	Accessibility per $ Jobs per Billion Dollars	Accessibility per $ People per Billion Dollars
Sheppard East LRT	3,073,384 (27%)	4,603,641 (18%)	27	13	1.0	3,073,384	4,603,641
Finch West LRT	2,210,307 (31%)	2,303,475 (20%)	19	11	1.0	2,210,307	2,303,475
Hurontario-Main LRT	1,989,043 (21%)	3,560,752 (23%)	26	23	1.6	1,243,152	2,225,470
Crosstown LRT	5,858,583 (25%)	11,215,243 (36%)	25	19	5.3	1,105,393	2,116,084
Crosstown LRT Ext.	1,822,517 (22%)	3,713,374 (22%)	18	11	1.7	1,072,069	2,184,338
TYS Subway	2,449,221 (74%)	2,350,027 (50%)	6	8.6	3.2	765,382	734,383
Hamilton B Line LRT	185,136 (8%)	220,390 (4%)	18	13.7	1.2	154,280	183,658
Scarborough Subway	82,041 (15%)	80,286 (6%)	1	7.6	3.56	23,045	22,552

[a] Absolute levels of change are provided as numbers of new jobs (active) and people (passive) reachable from and to the stations on each transit line. Percentage increases are provided in brackets below the absolute counts.

While the summary of accessibility changes provided in Table 3 is useful, it is clearly not an exhaustive demonstration of all the ways accessibility can be used to assess transit investments. In particular, due to our specific focus on development within transit stop catchment areas, we have limited our investigation to accessibility changes that occur at each transit stop. A more complete analysis of accessibility benefits could use a population-weighted measure of accessibility change over all demand zones in the region, such has been performed by a number of scholars in recent years (Farber & Fu, 2017; Foth et al., 2013; Jiang & Levinson, 2016).

Next, the composite accessibility score is mapped by tercile in Figure 4. Overall, the greatest gains in accessibility are attributed to stations along the Eglinton Crosstown LRT and the TYS Subway Extension. The lowest gains are found among the stations on the Hamilton LRT, the Scarborough Subway Extension, the Finch West LRT and parts of the Eglinton Crosstown Extension into Scarborough.

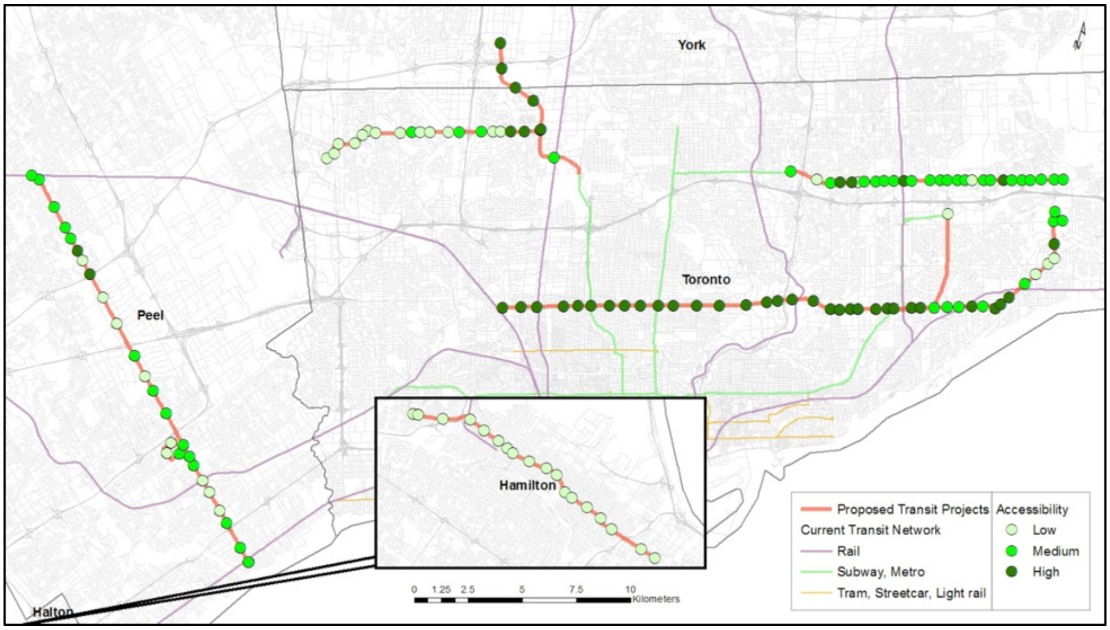

Figure 4: Map of composite accessibility scores

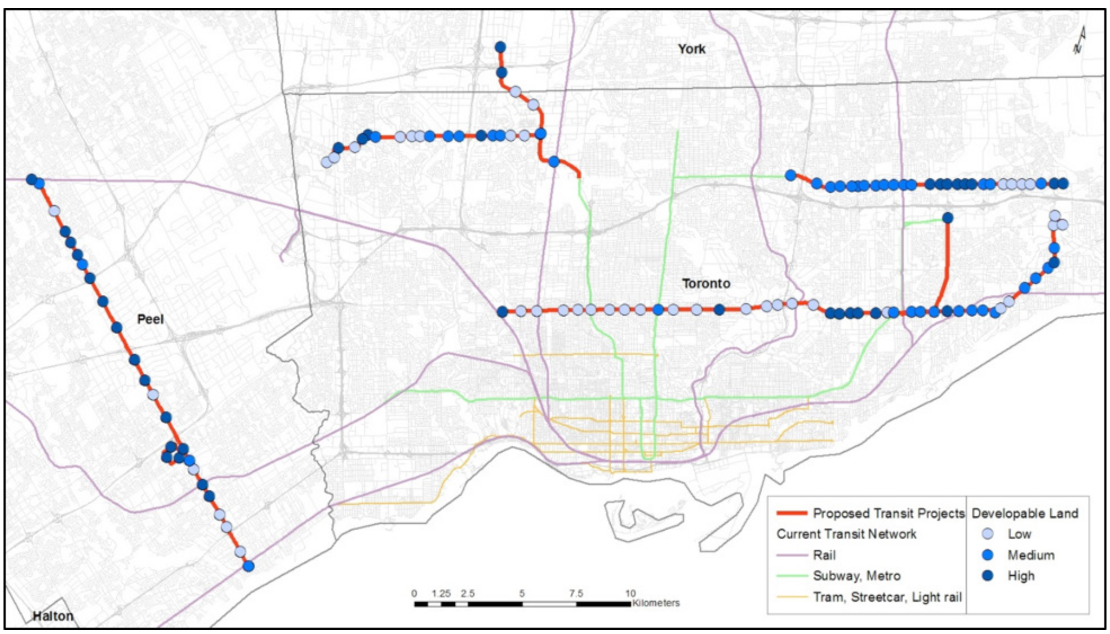

Figure 5: Map of developable land per station catchment area

5.3 Developable land

Figure 5 depicts the spatial distribution of developable lands within station areas. It is immediately observable (and perhaps concerning) that the Eglinton Crosstown LRT is home to most of the stations in the lowest tercile of available land. So, while this line scores very well in terms of accessibility gains, only the eastern and western extremities of this line have stations with high levels of developable lands. The suburban LRT lines consist of many stations with higher levels of developable land, largely due to them passing through older retail strips that are considered easily developable. In the MCE, it will become apparent whether there are stations that have both high levels of accessibility gains as well as availability of land to capitalize into redevelopments. Notice that land-use data were not available for the City of Hamilton, so the Hamilton LRT could not be included in the analyses involving developable lands.

5.4 Socioeconomic priority index

Figure 6 displays a map of the socioeconomic priority index. The stations have been depicted according to tercile membership of low, medium and high priority groups. The lowest priority station areas, according to socioeconomic need for transit, run through the core of the city along the Eglinton Crosstown LRT, in the northern half of the Hurontario-Main LRT, and the remainder being dispersed across the Region. The highest priority stations are clustered in downtown Mississauga (on the Hurontario-Main LRT), at the extremities of the Eglinton Crosstown and its eastward extension, and the rest along the Finch and Sheppard LRTs and the TYS Subway extension. Interestingly, almost all of the projects consist of stations that are at both ends of the socioeconomic priority scale, but it is yet to be seen how the socioeconomic priority index will interact with the accessibility index to determine which lines are actually providing higher levels of service to those most in need.

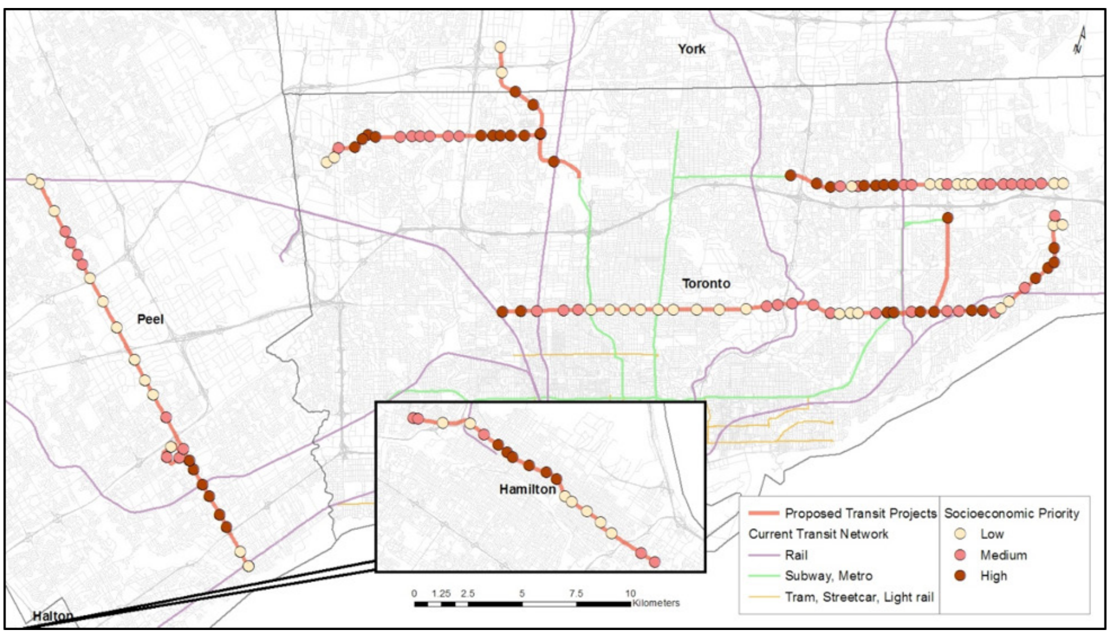

Figure 6: Map of the socioeconomic priority composite index

5.5 Multi-criteria evaluation

The three dimensions of analysis: accessibility, developable land, and socioeconomic priority, are each represented with a single composite index of their underlying measurements. Since Hamilton could not be included with the land-use category, but was included in the above descriptions of terciles for the accessibility and socioeconomic dimensions, the terciles for these two criteria need to be re-estimated to pertain only to the sample of 122 stations analyzed in the MCE. The final tercile breakpoints used in the MCE appear in Table 4.

Table 4: Tercile breakpoints used in the multi-criteria evaluation

Criteria	Min	33rd	66th	Max
Accessibility	-1.9	-0.8	0.4	6.3
Developable Land	0.0	9.0	16.0	59.5
Socioeconomic Priority	-3.5	1.9	3.4	8.1

All else being equal, each combination of Low, Medium, and High across the three dimensions should be found with equal probability of roughly 0.037, or about 4.5 stations per unique combination.

Table 5: A typology of stations based on (H)igh and (L)ow levels of (A)ccessibility, (D)evelopable land, and (S)ocioeconomic priority

Type	A	D	S	N	Description
1	H	H	L	7	High development potential and shifting to transit. No equity impact.
2	H	H	H	1	High development potential, positive equity impact but with a chance of gentrification.
3	H	L	L	8	High development signal but incorrect urban form. Wasted redevelopment potential but a chance for mode shifting. No equity impact.
4	H	L	H	6	Provision of high levels of accessibility to those most in need. Low redevelopment potential. Positive equity impact.
5	L	H	L	7	Low level of service in low priority neighborhood. No change expected.
6	L	H	H	7	Low level of service in high priority neighborhood. No change expected. Negative equity impact.
7	L	L	L	4	Low service. No redevelopment, no mode shifting, and no equity impact.
8	L	L	H	2	Low service. No redevelopment, no mode shifting, and negative equity impact.

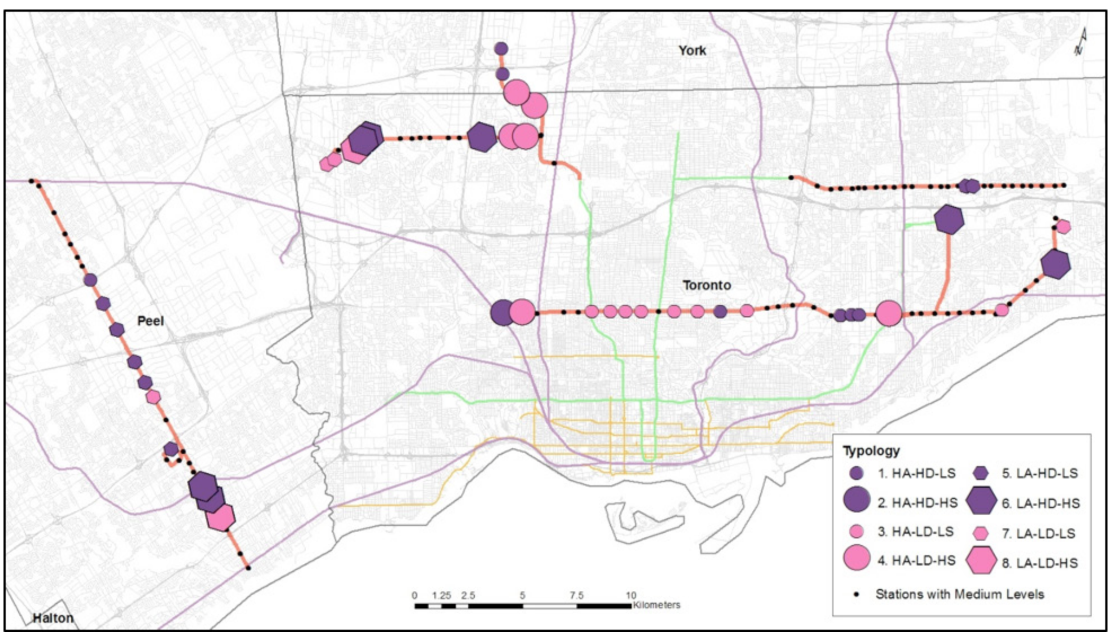

Figure 7: Map of station areas according to the typology found in Table 5. Shape depicts accessibility, color depicts developable land, and size depicts socioeconomic priority.

A typology of stations clearly follows from thinking about what High and Low mean for each dimension and their combinations. It will be convenient to use the following short forms: H=High, L=Low, A=Accessibility, D=Developable Land, and S=Socioeconomic Priority. A typology of combinations appears in Table 5, along with the observed number of stations in each category. We limit our focus to High and Low levels as those in the middle offer no strong signal in either direction and it is straightforward to produce interpretations for stations with Medium levels based on those provided in the table. A map of the stations appearing in the typology is presented in Figure 7.

Several general observations can be made by examining the distribution of stations into the types found in Table 5 or their counterparts including Medium-level outcomes as well. First, the relationship between accessibility and socioeconomic priority within station areas does not paint a positive picture. Within the high accessibility types, the most prominent are 1 & 3, consisting of stations that have high accessibility but low socioeconomic priority, indicating that transit services are not being directed to populations most dependent on the system. In total, there are 17 stations with high accessibility and low socioeconomic priority, 14% of the 122 included within our MCE. The expected number for such a pairwise combination is 3*4.5=13.5 stations (or 11%). Contrastingly, there are only 12 stations (10%) that score high on accessibility and socioeconomic priority at the same time, while there are 17 stations with low accessibility and high socioeconomic priority. In total, it appears that more accessibility is being offered to lower priority neighborhoods, according to socioeconomic status.

Second, there is evidence of a mismatch between accessibility and the availability of developable land. When looking at the concurrence of high accessibility and developable lands, we see only 10 such stations in the region (8% of total). And when accessibility is high, but developable lands are low, we observe 21 stations, or 17% of the total. This is the most frequent pairwise combination found in the study, indicating a poor overall coordination of transit with land-use development potential in the region. One potential reason for the apparent lack of coordination is that there have been few transit investments in the GTHA over the past decades, and now the proposed lines are bringing much needed services to already built-up areas. For example, the HA-LD stations are mostly along the Eglinton Crosstown LRT (16 stations), which passes primarily through already built-up areas in the center of the city. The next most frequent pairwise combination are stations with low accessibility and high developable lands (19 stations or 16% of total), indicating again a mismatch between accessibility and future development of land use.

Third, we can investigate the relationship between developable land and socioeconomic priority. We claim that the interpretation of this relationship is moderated heavily by the occurrence of high or low accessibility gains brought by the transit projects. In particular, when accessibility gains are low, there is little signal for redevelopment and the effect on populations, in terms of gentrification are diminished. However, when accessibility gains are high, there is concern that gentrification could occur in high priority neighborhoods that likewise have a high degree of developable land. According to this analysis, there is only one station with HA, HD and HS, Mount Dennis Station, the western terminus of The Eglinton Crosstown, and a location with intensification and gentrification already in progress (Bamforth, Grández, Krushnisky, Macher, & Santos, 2015; Lorinc, 2012; Paperny, 2012). So, while there are concerns over gentrification in the region regarding new transit infrastructure, according to this assessment, the newly proposed projects appear to be benign on this front. Adding that the socioeconomic characteristics of the catchment areas are, on average, of much higher priority than the rest of the GTHA region (according to Table 2), the proposed transit plans are likely to have a net positive impact on equity in the region.

6 Conclusions

In this research, we evaluated a set of 8 transit plans in the GTHA on the criteria of accessibility change, the availability of developable land, and the socioeconomic priority of the station areas. Our approach involved the innovative coding of the future transit network within a routable GIS network dataset, allowing for the accurate accounting of the number of jobs accessible from each station, and the number of people that can reach each station, both within a 50-minute travel time threshold. These cumulative accessibility scores, considered active and passive measures of accessibility, are theorized to impact redevelopment potential within station areas. This is the first time accessibility has been calculated for the proposed transit plans in the GTHA. Therefore, this research provides an important empirical base for evaluating the interactions of transit development with socioeconomics and land development potential. Although computing accessibility and accumulating other variables for each transit station area required considerable technical expertise, the results presented are mostly descriptive. However, as a useful contribution to transportation/land-use theory, we provide a novel typology for proposed transit stations via the implementation of a multi-criteria analysis.

One methodological drawback to this research project is that accessibility measures do not account for changes in the land-use system; we implicitly assume that population and employment distributions are stable between the before and after scenarios tested. Unfortunately, forecasted population and employment figures are not readily available for the region. Such estimates exist at the macro scale for municipalities within the region, but downscaling to the spatial resolution required to make them useful in this accessibility analysis was not possible within the context of this research project. Producing long-range population and employment forecasts at a small level of geography, especially if one is concerned with the effects of new transit infrastructure in the region as we are in this project, would require a shift to an integrated transportation/land-use simulation of the GTHA. While such systems exist in another research unit at our University, the type of network modifications tested in this research would require weeks of additional work in producing Emme-based networks and travel times. The drawback of not considering future land-use patterns is that we are underestimating accessibility increases that may occur due to land-use intensification near the transit station areas, or elsewhere in the region that will be connected by the new transit infrastructure.

Our results are summarized according to the performance of the station areas on each input criteria as well as their pairwise and three-way combinations. With this approach, it was possible to make certain conclusions regarding the transportation infrastructure planned for this region. First, because of the mismatch between where accessibility gains will be highest, and where land is most available, the transit plans seem poorly poised to integrate with future land-use development in the region. Second, because only a few station areas with high accessibility gains also have high socioeconomic priority, it seems that the transit plans are not overwhelmingly well situated to address transportation equity concerns in the region. And third, there is only one station where, according to our typology, gentrification is likely to be of major concern.

To contextualize these results, it is important to note that the transportation planning authorities have already conducted fairly detailed business case analyses of all of the transit plans incorporated into this study. In these cases, the ability for transit projects to attract ridership and to result in mode-shifting have been the major foci of evaluation. While we advocate for the use of such assessment metrics, in addition to assessments of environmental and congestion benefits associated with mode-shifting, the accuracy of many of these analyses have been contested by the media, by local academics, by politicians, and by transit activists in the region. It is our intention to add novel empirical evidence concerning the additional factors of accessibility, land development, and socioeconomic priority.

7 Acknowledgements

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Appendix 1: Enumerated results for all station areas in the GTHA

	Z Scores			Terciles		
	Accessibility	**Developable Land**	**Socioeconomic Priority**	**Accessibility**	**Developable Land**	**Socioeconomic Priority**
Eglinton Crosstown LRT						
Mount Dennis	3.18	16.99	3.85	High	High	High
Keelesdale	2.86	4.78	3.66	High	Low	High
Fairbank (Dufferin)	3.67	8.06	2.35	High	Low	Medium
Caledonia (Blackthorn)	1.85	6.24	2.56	High	Low	Medium
Oakwood	2.66	4.81	2.17	High	Low	Medium
Cedarvale (Eglinton West Stn)	0.53	3.52	1.49	High	Low	Low
Forest Hill (Bathurst)	3.44	1.72	0.99	High	Low	Low
Chaplin	2.68	2.41	0.83	High	Low	Low
Avenue	1.90	2.86	-0.84	High	Low	Low
Eglinton (Yonge)	1.54	9.63	0.70	High	Medium	Low
Mount Pleasant	1.92	4.89	0.67	High	Low	Low
Leaside (Bayview)	2.94	4.14	-2.07	High	Low	Low
Laird	3.86	16.91	-0.06	High	High	Low
Sunnybrook Park (Leslie)	3.42	5.87	1.61	High	Low	Low
Science Centre (Don Mills)	2.77	3.74	3.11	High	Low	Medium
Aga Khan Park & Museum (Ferrand)	3.90	1.78	2.82	High	Low	Medium
Wynford	2.73	5.27	2.67	High	Low	Medium
Sloane	2.99	0.11	3.29	High	Low	Medium
O'Connor (Victoria Park)	1.66	18.71	3.22	High	High	Medium
Pharmacy	0.70	30.72	1.71	High	High	Low
Hakimi Lebovic	4.79	59.47	-0.20	High	High	Low
Golden Mile (Warden)	0.66	52.52	-0.68	High	High	Low
Birchmount	2.35	18.73	3.24	High	High	Medium
Ionview	1.38	7.31	4.42	High	Low	High
Kennedy	0.53	10.43	4.55	High	Medium	High
Eglinton Crosstown LRT Extension						
Midland	0.59	12.21	3.13	High	Medium	Medium
Falmouth	0.42	14.38	3.89	High	Medium	High
Danforth	-0.06	15.36	5.58	Medium	Medium	High
McCowan	-0.10	16.12	3.41	Medium	High	Medium
Eglinton GO (Bellamy)	-0.11	13.89	2.06	Medium	Medium	Medium
Mason	0.70	14.74	4.11	High	Medium	High
Markham	-0.99	14.74	5.46	Medium	Medium	High
Eglinton/Kingston	0.13	10.97	3.10	High	Medium	Medium
Golf Club	0.99	6.34	1.75	High	Low	Low
Guildwood	0.36	4.48	-0.35	High	Low	Low
Guildwood	-0.79	10.82	1.95	Medium	Medium	Medium
Galloway	-1.16	11.28	3.42	Low	Medium	High
Lawrence	-1.48	14.63	5.14	Low	Medium	High
Kingston/Morningside	-1.41	17.05	5.61	Low	High	High
West Hill	1.38	10.58	4.89	High	Medium	High
Ellesmere	-0.34	1.23	1.21	Medium	Low	Low
University	-0.93	1.30	-0.26	Medium	Low	Low
Military Trail	-0.44	1.06	1.88	Medium	Low	Medium

Appendix 1: Enumerated results for all station areas in the GTHA *(continued)*

	Z Scores			Terciles		
	Accessibility	Developable Land	Socioeconomic Priority	Accessibility	Developable Land	Socioeconomic Priority
Finch West LRT						
Humber College Terminal	-1.49	3.39	1.62	Low	Low	Low
Highway 27	-1.62	8.13	1.54	Low	Low	Low
Westmore Dr	-1.58	16.26	2.58	Low	High	Medium
Martin Grove	-1.48	8.46	4.65	Low	Low	High
Albion	-1.28	16.00	5.63	Low	High	High
Stevenson	-1.12	24.78	6.13	Low	High	High
Kipling	-1.52	12.94	6.01	Low	Medium	High
Islington	-1.29	2.40	2.67	Low	Low	Medium
Pearldale	0.11	4.15	2.27	Medium	Low	Medium
Duncanwoods	-1.13	8.09	2.29	Low	Low	Medium
Milvan/Rumike	-1.30	10.12	3.05	Low	Medium	Medium
Weston	-1.44	9.66	3.08	Low	Medium	Medium
Signet/Arrow	-0.25	9.94	1.93	Medium	Medium	Medium
Norfinch/Oakdale	-0.92	19.19	3.51	Medium	High	High
Jane	-1.10	15.81	4.92	Low	Medium	High
Driftwood	-1.33	12.29	5.31	Low	Medium	High
Tobermory	1.94	4.84	5.04	High	Low	High
Sentinel	2.35	1.04	5.38	High	Low	High
Keele Stn	3.76	9.68	6.58	High	Medium	High
Hamilton B Line LRT						
Parkdale	-2.31	NA	0.83	Low	NA	Low
Nash	-2.00	NA	2.00	Low	NA	Medium
Eastgate	-2.12	NA	2.59	Low	NA	Medium
McMaster	-2.18	NA	3.20	Low	NA	Medium
McMaster Hospital	-1.77	NA	3.22	Low	NA	Medium
Longwood	-2.22	NA	1.84	Low	NA	Low
Dundurn	-2.19	NA	0.62	Low	NA	Low
Queen	-2.26	NA	3.40	Low	NA	Medium
Walnut	-2.17	NA	6.72	Low	NA	High
Gore Park	-2.31	NA	5.98	Low	NA	High
Wenthworth	-2.24	NA	7.57	Low	NA	High
Wellington	-2.06	NA	7.66	Low	NA	High
The Delta	-2.12	NA	-1.79	Low	NA	Low
Ottawa	-2.31	NA	-1.38	Low	NA	Low
Sherman	-2.06	NA	7.37	Low	NA	High
Prospect	-2.13	NA	6.12	Low	NA	High
Kenilworth	-2.19	NA	-0.78	Low	NA	Low
Queenston	-1.93	NA	0.24	Low	NA	Low
Hurontario-Main LRT						
Nanwood	-0.52	5.66	-0.57	Medium	Low	
Queen	-0.44	13.10	1.41	Medium	Medium	
Brampton GO	-0.33	17.83	1.30	Medium	High	
Cooksville GO	-1.13	24.13	3.93	Low	High	
Central Parkway	-0.72	7.78	4.50	Medium	Low	

Appendix 1: Enumerated results for all station areas in the GTHA *(continued)*

	Z Scores			Terciles		
	Accessibility	Developable Land	Socioeconomic Priority	Accessibility	Developable Land	Socioeconomic Priority
Duke of York	-1.42	39.82	2.07	Low	High	Medium
Rathbutn	-1.57	37.55	1.49	Low	High	Low
Main	-0.72	24.43	3.29	Medium	High	Medium
Matthews Gate	0.00	15.22	4.10	Medium	Medium	High
Robert Speck	-1.04	25.20	2.58	Medium	High	Medium
Mineola	-0.50	6.63	-3.16	Medium	Low	Low
Queensway	-1.44	7.11	6.51	Low	Low	High
North Service	-0.40	8.49	5.82	Medium	Low	High
Port Credit Go	-1.09	14.51	-0.09	Medium	Medium	Low
Dundas	-1.53	28.53	5.25	Low	High	High
Courtneypark	-1.63	33.67	1.09	Low	High	Low
Derry	-1.35	39.57	0.85	Low	High	Low
Eglinton	-0.56	33.55	2.15	Medium	High	Medium
Matheson	-1.11	26.37	0.24	Low	High	Low
Bristol	-0.99	5.92	1.61	Medium	Low	Low
Britannia	-0.94	29.34	0.30	Medium	High	Low
Sir Lou	0.34	25.34	2.78	High	High	Medium
Highway 407	1.31	19.60	1.34	High	High	Low
Ray Lawson	-1.70	12.89	2.40	Low	Medium	Medium
Getway Terminal	-0.87	31.64	2.73	Medium	High	Medium
Charolais	-0.81	24.19	2.60	Medium	High	Medium
Scarborough Subway						
Scarborough Centre Stn	-1.11	27.39	4.16	Low	High	High
Sheppard East LRT						
Don Mills Stn	-0.91	14.27	6.84	Medium	Medium	High
Consumers	-1.44	11.54	3.95	Low	Medium	High
Victoria Park	-0.24	13.89	3.50	Medium	Medium	High
Pharmacy	1.70	11.50	2.11	High	Medium	Medium
Palmdale	0.86	11.21	1.82	High	Medium	Low
Warden	-1.87	10.73	2.64	Low	Medium	Medium
Bay Mills	-0.27	8.80	3.74	Medium	Medium	High
Birchmount	-0.77	8.98	4.33	Medium	Medium	High
Allanford	-0.04	10.79	4.20	Medium	Medium	High
Kennedy	-0.56	12.46	4.07	Medium	Medium	High
Agincourt	0.14	15.53	3.31	High	Medium	Medium
Midland	0.11	14.12	2.49	Medium	Medium	Medium
Brimley	-0.61	17.34	0.99	Medium	High	Low
Brownspring	-0.26	21.71	1.75	Medium	High	Low
McCowan	0.07	21.89	1.86	Medium	High	Medium
White Haven	-0.37	25.51	1.60	Medium	High	Low
Shorting	-1.06	18.38	1.53	Medium	High	Low
Massie	-1.39	18.75	1.63	Low	High	Low
Markham	-0.04	14.86	2.06	Medium	Medium	Medium
Malvern/Progress	-0.06	13.22	2.38	Medium	Medium	Medium
Washburn	0.19	2.98	2.69	High	Low	Medium

Appendix 1: Enumerated results for all station areas in the GTHA *(continued)*

	Z Scores			Terciles		
	Accessibility	**Developable Land**	**Socioeconomic Priority**	**Accessibility**	**Developable Land**	**Socioeconomic Priority**
Burrows Hall	-0.20	2.91	2.63	Medium	Low	Medium
Neilson	0.04	0.89	2.70	Medium	Low	Medium
Murison	-0.08	0.00	2.22	Medium	Low	Medium
Brenyon	-0.32	11.35	2.17	Medium	Medium	Medium
Morningside	-0.33	22.61	1.65	Medium	High	Low
Water Tower Gate	-0.07	30.46	1.51	Medium	High	Low
Toronto-York Spadina Extension						
Highway 407	3.03	16.49	-3.53	High	High	Low
Finch West	4.59	10.01	6.70	High	Medium	High
Black Creek Pioneer Village	6.31	2.59	7.42	High	Low	High
York University	5.10	6.10	8.09	High	Low	High
Downsview Park	-0.39	10.92	8.09	Medium	Medium	High
Vaughan Metropolitan Centre	2.99	49.54	-3.53	High	High	Low